Soos Creek Hatchery – Duwamish River Estuary combination, yielding a similar result (77% for Soos Creek hatchery and 59% for the Duwamish River estuary fish).

Three experiments in 1993 and 1994 examined susceptibility of juvenile Chinook to a common marine pathogen (*Vibrio anguillarum*) (Arkoosh et al. 1998). The 1993 experiments were conducted in two phases whereby one group was tested 1 month after capture and the second group was allowed 2 months to depurate contaminants. Fish were collected from the Nisqually delta and Duwamish River and their respective hatchery (Kalama and Soos Creek) and exposed to the pathogen for 1 h. For both years, fish from the Duwamish waterway exhibited substantially higher mortality at 4 and 7 days post pathogen exposure compared with fish from their respective hatchery. There was no difference in mortality for these time points or sampling years for fish from the Nisqually hatchery and estuary. Mean concentrations of PAHs and PCBs in the stomachs and liver of fish from composited samples (n = 60 fish per composite) from these estuaries and hatcheries at the time of collection were very similar to those reported in Table 2 (current study), except for the PAH concentrations, which were lower, ranging between 5 and 10 $\mu g \cdot g^{-1}$ (wet mass) for the Duwamish fish. These results are supported by a laboratory study, with fish from these same hatcheries and estuaries demonstrating altered immune parameters (Arkoosh et al. 1991).

Contamination in adult Chinook

Any adverse responses resulting from exposure to contamination are likely to occur in juveniles and not adults. Because water and prey in open marine waters contain less contamination than found within estuaries, concentrations of most toxicants likely decline because of growth dilution, which has been demonstrated for PCBs in salmon from Puget Sound (O'Neill and West 2009). Therefore, the focus for this analysis is on factors that may affect first-year survival when contaminated fish are most susceptible. Theoretically, returning adult salmon could accumulate contaminants to adverse levels; however, there is no evidence to support this hypothesis. One recent study assessed PCB concentrations in returning adult Chinook salmon to Puget Sound rivers and found relatively low concentrations in terms of lipid normalized concentrations (mean 53 $ng \cdot g^{-1}$ (wet mass fillet), lipid 5.4%) in fish from the Nooksack, Skagit, Duwamish, Nisqually, and Deschutes rivers (O'Neill and West 2009). Also, returning adult Chinook do not feed prior to, or within, the local estuary when in their reproductive mode (Higgs et al. 1995), and therefore it is unlikely that potential contamination at this life stage can explain the SAR values.

Implications for wild fish

If contamination is indeed the causative factor limiting the SAR for hatchery Chinook, then the extended time expected for naturally reared Chinook may lead to even more dramatic impairment. This is also relevant for any other salmonid at this life stage that may reside in an estuary for an extended time. If this level of reduction in survival for wild fish outmigrating through contaminated estuaries is occurring, it will likely manifest in large changes to population abundance and structure as demonstrated with life history modeling (Spromberg and Meador 2005). As shown by Spromberg and Meador (2005), first-year survival is the most important period of the Chinook life cycle, and increases in mortality as low as 10% can result in a substantially reduced population growth rate for this species, given that impacts (e.g., reduced growth or elevated mortality) occur over several generations.

Five or more life history trajectories have been identified for Chinook salmon (Ruggerone and Weitkamp 2004), including the numerous smolts that migrate in May and June and spend several days to weeks in the estuary. Also identified are fry migrants that can spend weeks to months in the estuary before migrating out to marine waters. One study determined that wild juvenile Chinook spend approximately twice as long in the estuary as do hatchery fish (Levings et al. 1986), which would likely increase their exposure to harmful chemicals. The degree of unaltered habitat is an important factor to consider for naturally reared Chinook, which are likely more susceptible to habitat modifications compared with hatchery fish.

Next steps

Considering the large effort and resources devoted to understanding the factors that affect salmonid success in an attempt to rebuild depleted stocks, contamination of their natal estuaries receives very little attention. The impact of environmental toxicants on aspects of fish health such as growth rate, lipid stores, susceptibility to pathogens, altered behavior, and physiological changes both in the laboratory and field should be considered for any evaluation of population vitality. Defining toxicity for myriad contaminants found in urban estuaries and studies that evaluate the health of juvenile salmon will provide much-needed information for source control and remediation of contaminated estuaries, which is expected to improve cohort survival. Concentrations of chemicals in fish tissue can be quite valuable for assessing toxic effects (Meador et al. 2008*b*), and there are data available now for several chemicals (Beckvar et al. 2005; Meador 2006; McElroy et al. 2011).

It is clear that a simple binary designation for estuary status in terms of chemical contamination is insufficient for focused risk assessments and determining when harm is reduced. Unfortunately, there are few data available that can be employed for such evaluations. A concerted effort to characterize toxicant exposure is required to allow for finer scale categorization of estuary status. Extensive datasets on fish tissue concentrations of suspected harmful chemicals are needed for characterizing exposure, toxicity evaluation, and determining the degree of remediation success. Studies highlighting water and sediment concentrations are also necessary for gauging exposure and determination of cleanup levels. Primary consideration should be given to tissue (fish and stomach contents) and water concentrations, which can be more easily linked to toxic effects. Additional metrics to consider in future studies include the location of wastewater treatment plants and combined sewer overflows, runoff from impervious surfaces, and potential inputs from pesticide applications and waste from industrial animal production. As more data become available, successive analyses should include weighting factors for each metric and possibly a summation style index describing the state of contamination for each estuary.

The results of this analysis in no way diminish the conclusions of other studies and their findings relating salmonid survival to habitat characteristics (e.g., shoreline armoring, loss of intertidal habitat, and reduced flow) or biological interactions (e.g., effects of competition), but instead raise the possibility of yet another potentially important factor that should be considered in conjunction with all other known determinants. Remediation efforts for compromised estuarine areas usually consider myriad factors during design and implementation, and as shown in this study, contamination should be included as one of those important determinants. Understanding and characterizing chemical contamination in our estuaries is just one crucial and necessary aspect of advancing efforts for the recovery of salmon populations.

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